Executive Summary

This study examined ecological and economic concepts relevant to improving environmental benefits analysis, and recommends a strategy for improving related tools, application capabilities, policy and guidance. In planning ecosystem restoration projects, the Corps uses non-monetary indicators of benefit in cost-effectiveness analysis and incremental analysis, rather than economic benefit-cost analysis. These non-monetary indicators can be supplemented by consideration of incidental monetary benefits. In cases of joint formulation for contributions to both National Ecosystem Restoration (NER) and National Economic Development (NED), formulation and evaluation uses a combination of monetized NED outputs and non-monetized NER outputs. Ideally, all significant effects from projects would be expressed in the same unit-measure, but technical limitations currently impede this. Analytical difficulty escalates as the number of outputs considered increases, thus, a significant challenge in ecosystem restoration planning is reducing the number of different outputs considered in cost-effectiveness analysis to a manageable number of those most significant.

The study confirmed what Corps policy has concluded—that planning principles for NER and NED objectives are essentially the same, except for "limitations in understanding the complex inter-relationships of the components of ecological resources and services", and except that "the environmental outputs...are typically not monetized." Two different premises for guiding pursuit of ecosystem restoration were found. One is skeptical of human management toward specified ends, favoring instead to simply remove the sources of human effect, then, let nature take its course, whatever that may be. Implicit is value on the unspecified range of natural outcomes that results. The other premise places more faith in human enterprise, emphasizing benefits from a set of resource services using habitat improvement measures that simulate nature (the naturalistic approach) as well as natural features and processes. Corps policy includes elements of both premises, but does not clearly address interrelationships of naturalness, resources and services – appearing to emphasize restoration to a more natural condition, but urging examination of significant outputs in evaluation.

The study reviewed existing concepts of ecological resource and service flows, including numerous interrelationships regarding ecosystem structure, function, integrity, sustainability, health, resilience, functional stability, and biodiversity. Of those, biodiversity proved to be most inclusive concept underlying indicators of ecosystem naturalness and human effect, once calibrated against an array of reference conditions with varying degrees of human effect. The study revealed no widely applicable environmental (non-monetary) indicator of human benefit. However, a "biodiversity scarcity index", based on the uniqueness and vulnerability of species and their associated genetic information, deserves further consideration as an inclusive indicator of NER contributions. No ideal models and methods for ecosystem restoration planning exist at this time, but several types of biodiversity-based models and methods can be used cautiously in the interim, even though they have substantial limitations. Only rarely will an existing single model be comprehensive enough for complete evaluation, especially when the resources recognized for their social significance comprise a subset of the biotic community. Despite these limitations, many advances in recent years now allow development of much improved models.

The study also concludes that no fully inclusive monetary measure of ecosystem restoration effects now exists, and that significant technical obstacles currently preclude the economic valuation of all restoration outcomes. This suggests that the current policy guidance that recognizes non-monetary NER outcomes as a category of effects separate from monetary effects will continue to be appropriate for the foreseeable future. The cost-effectiveness analytical framework is very useful, even when outputs are expressed in multiple, non-commensurate metrics, including joint NER/NED planning. However, analytical complexity increases as the number of non-commensurate metrics increases beyond two or three, making pursuit of inclusive metrics important. A proposed strategy focuses on this pursuit through coordinated improvement of techniques, policy and guidance, and practitioner capabilities.

The proposed strategy involves overlapping (I) *near-term, (II) intermediate,* and *(III) long-term* components, all of which would start immediately. The *near-term* or **Incremental** component (2 to 3 year horizon), addresses the requirements of the current Corps planning regulations and emphasizes broadened staff proficiency and selection and application of existing ecological assessment models. Elements include:

- Greater use of community-habitat models instead of emphasis on single-species habitat models.
- Improving guidance on model selection and use.
- Incorporating the concepts of and approaches to environmental benefits analysis into courses, workshops and other forums designed to enhance staff capabilities.
- Refining policy and guidance pertaining to ecological and methodological concepts and the concept of NER.

The *intermediate*, or **Next Generation** component (5-year horizon), pursues a fundamental rethinking of the NER objective and desired outputs, including possible specification of ecological services in the definition of an NER account, improvement of multiple-output evaluation models based on simulation of geophysical and ecological process understanding, and exploration of new analytical frameworks for multipurpose NED/NER planning. Elements include:

- Developing and refining multi-output ecosystem simulation models consistent with improvements in Corps plan evaluation frameworks.
- Further investigating and developing a metric based on the scarcity of biodiversity resources to indicate NER contributions.
- Refining baseline and strategic R&D programs to include wider applications of existing planning models and development of appropriate new models.
- Refining the NER concept and analytical frameworks for joint NED/NER projects relative to the concept of ecosystem services, sustainability, and the "NEPA process" in pursuit of more consistent evaluation standards.

Over a *longer-term* (10+ year horizon), efforts could be made to explore pursuit of economic valuation of ecosystem services. This **Monetization** component attempts to allow more NER outcomes to be evaluated in NED terms, thereby reducing the total number of non-commensurate choice criteria that would need to be considered for efficiency analysis. Elements include:

- Examining the technical obstacles including uncertainties in forecasting ecological outputs, and limitations in measuring non-marketed goods.
- Developing technically and politically acceptable estimates of monetary value for restoration effects when practicable for use in the CE/ICA framework.

Report Summary

Introduction

The U.S. Army Corps of Engineers (Corps) now pursues ecosystem restoration as a priority Civil Works purpose on par with traditional economic development purposes such as commercial navigation and flood damage reduction. But whereas the Corps planning framework applied to economic development purposes requires a monetary standard for project evaluation, the framework established for ecosystem restoration planning stipulates that restoration project outputs are to be measured and expressed in non-monetary metrics.

The recent emphasis on assuring returns from Federal investments, along with the reality of budgetary constraints, have resulted in a renewed interest in the methods used to evaluate the outputs of environmental projects and programs. Importantly for the Corps, the adequacy of the methods currently being used within the Civil Works program for characterizing and evaluating the environmental outputs of ecosystem restoration projects has been questioned in a number of forums (e.g. NRC (1999), OMB).

Purpose

This report identifies and examines policy and technical issues related to improving environmental benefits analysis for Civil Works planning. As used here, the term "environmental benefits analysis" refers to the development of an evaluation philosophy, framework and complementary analytical tools to aid Corps restoration project planning, but is *not* intended to imply a planning process that involves estimating dollar values for restoration outputs.

The primary report focus relates to the identification and assessment of alternative metrics and analytical procedures for characterizing and evaluating restoration project outputs in non-monetary terms. A secondary focus relates to the identification and assessment of alternative plan comparison frameworks for projects plans formulated at least in part to serve ecosystem restoration. With regards to these issues, the report addresses the following questions:

- What non-monetary metrics of environmental quality change may have wide applicability for characterizing and evaluating ecosystem restoration outputs?

- What plan comparison frameworks and procedures are available for plans formulated to serve ecosystem restoration as well as mixed economic and environmental objectives, and what are their strengths and weaknesses for illuminating the economic efficiency implications and tradeoffs among plans?

Civil Works Ecosystem Restoration: What, How and Why?

Section 2 describes the planning framework established for civil works ecosystem restoration. It outlines the basic guidance established for civil works ecosystem restoration planning, and examines possible implications for characterizing and evaluating restoration outputs.

Focus of Ecosystem Restoration

Corps environmental management expertise generally centers on the hydrology and geomorphology of aquatic systems. Corps restoration projects typically focus on significant water and related land resources of river and coastal ecosystems, including their associated floodplains, shores, and wetlands. The boundaries of these natural systems typically define the appropriate focus of all civil works activities, including traditional flood control and navigation projects as well as ecosystem restoration activities. But whereas traditional civil works projects generally rely on management measures to eliminate hydrologic extremes, ecosystem restoration generally requires measures to re-establish natural hydrologic variability.

Objectives of Ecosystem Restoration

Civil works activities alter the structure and processes of ecosystems. The evaluation of such alterations for decision-making purposes requires a standard of value for measuring the outcome associated with such change. That valuation standard should follow logically from the stated objective in civil works planning.

In traditional civil works planning, the federal objective is defined as utilitarian; that is, to contribute to the satisfaction of human preferences. Economic value provides an empirical "account" of the contribution of civil works activities to preference satisfaction, and represents the standard of value specified by Corps guidance for the evaluation of traditional civil works projects. Further, Corps guidance specifies the specific purposes -- or desired outputs -- to be served by traditional civil works projects. These traditional outputs can be viewed in terms of closely related "ecosystem services".

Ecosystem services have been defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Dailey, 1997). As this definition implies, ecosystem services can be viewed as the link between the natural properties of ecosystems and human benefits. That is, the service concept connects an ecological focus on "what ecosystems do" with an economic focus on how ecosystems contribute to the satisfaction of human preferences. As such, the concept embodies both an ecological dimension and a human dimension. Box ES-1 provides a list of example ecosystem services and the various ways in which they can contribute to economic value.

Traditional civil works purposes include many of the production and consumption activities listed in the right hand side of Box ES-1, and these in turn are closely linked to one or more underlying ecosystem services listed on the left side of the table. Indeed, it is these associated ecosystem services that are the focus of plan formulation for traditional civil works projects. So, for example, commercial navigation projects focus on intensive enhancement of natural waterway transportation links, and flood damage reduction projects focus on enhancement of the natural flood regulation service.

<table>
<tr><th colspan="3">Box ES-1. Example Ecosystems Services and Associated Human Uses & Benefits</th></tr>
<tr><th>Ecosystem Services</th><th colspan="2">Channels Through Which Ecosystem Services Contribute to Economic Value</th></tr>
<tr><td rowspan="3">• Disturbance Regulation (flood, wind & wave)
• Waterway Transportation Links
• Water Storage
• Water Purification
• Sediment Trapping
• Waste Treatment
• Biological Pest Control
• Climate Regulation
• Rare and Unique Species/Genetic Store
• Wildlife Support (e.g., food chain, nursery)</td><td>Direct Passive Use</td><td>• Personal satisfaction derived from the knowledge that rare ecosystems & associated functions & services are intact, independent of any actual or anticipated active use</td></tr>
<tr><td>Direct Consumption</td><td>• Community Flood & Storm Protection
• Municipal & Residential Water Supply
• Consumptive & Non-consumptive Recreation
• Aesthetics, Observation & Study</td></tr>
<tr><td>Production Inputs</td><td>• Land Productivity for Agriculture
• Commercial Navigation
• Hydroelectric Power Generation
• Water Input for Agriculture & Industry
• Commercial Fishing, Hunting/Trapping, etc.</td></tr>
</table>

While the relationship between ecosystem services and the traditional civil works objective and specific purposes is straightforward, the relevance of services to the ecosystem restoration mission is not as apparent. Corps planning regulations and supporting policy documentation specify that the federal objective in ecosystem restoration is to “increase the net quantity and/or quality of desired resources” through the restoration of “significant ecosystem function, structure and dynamic processes that have been degraded”. The relevance of ecosystem services for the restoration mission depends on how this objective statement is interpreted in terms of desired ends. At least two possible motives for movement along a restoration path can be identified.

First, restoration might be sought purely for utilitarian reasons, implying a concern for services that people value. That is, management actions might seek to restore the hydrologic conditions thought necessary to secure a mix of ecosystem services and associated human benefits only because that is the best plan for reestablishing deficient services. But, when services ordinarily associated with a more natural condition are better gained by artificial means, a simulation of natural measures—a naturalistic approach—or even a highly artificial plan, might be chosen. The approach to restoration might be called “the manager knows best” approach and is based on careful analysis of resource and service flow from a variety of natural and artificial management measures. Natural ecosystem services can produce economic value in a variety of ways. In the extreme, a person may gain individual utility from, and thus be willing to pay for, the mere knowledge that a resource and associated services are maintained in good condition. Such assurance is said to produce “passive use value” that is independent of current or future plans for use. By contrast, “use value” is generated when people actively use ecosystems services by consuming them directly or as inputs into commercial production. For example, restoration can augment water purification and wildlife support services that generate use value directly by improving recreation opportunities, and indirectly by supporting commercial fisheries. Restoration of nature's services can also generate use value in more subtle and indirect ways by supporting general economic and social activity. For example, services such as climate regulation, sediment trapping, and waste treatment support and prevent damage to a wide range of consumption and production activity.

A second possible motive for pursuing restoration is the "naturalness" of ecosystem hydrology and geomorphology, as an end in itself. This approach is not independent of the resulting mix of service flows, but assumes that whatever results ecologically is more acceptable than the results from any other alternative. This might be called a "nature knows best" approach. It ignores the service flows from proposed management measures based on the *a priori* judgment that no better plan alternative exists. On the surface at least, this seems to be the position of some environmental interest groups that advocate a return to free-flowing rivers in certain contexts. The notion that naturalness is an independent value to be advanced by civil works planning is at odds with the traditional civil works objective rooted in utilitarianism, but represents one plausible motivation for Corps restoration activities.

Evaluation of Ecosystem Restoration

Corps planning guidance does not specifically establish the goal of restoration as naturalness as end in itself, or as a means to support desired natural service outcomes. Instead, Corps regulations emphasize the "significance" of resources and effects for guiding restoration planning. The significance concept is defined in terms of institutional, public or technical recognition, and as such seems broad enough to include both naturalness and associated services as desired restoration ends.

Corps regulations specify that restoration outputs must be evaluated in non-monetary metrics, with preference given to "units that measure an increase in ecosystem value" that are indicative of the social significance of project effects. To the extent that significance in any particular restoration context relates directly to some natural ecosystem condition (e.g., a free-flowing riverine ecosystem), then metrics indicating a change towards that natural state may be all that is needed for project evaluation. On the other hand, if significance relates to specific ecosystem component parts or processes by virtue of their links to valued services (e.g., a particular fish species), then project evaluation may need to include metrics indicating the desired direction of change in these components.

Ecological Concepts Underlying Environmental Benefits Analysis

Section 3 presents and discusses ecological concepts and theory relevant for restoration planning. It reviews the relevancy of ecological concepts to consideration of ecosystem-output indicators of ecological "value", and considers their potential to provide a basis for defining a single ecological metric for characterizing and evaluating restoration benefits.

Holistic views of natural ecosystem structure, function, and other processes are expressed through various concepts, including ecosystem integrity, biodiversity, self-regulation, resilience, stability, sustainability, production, and materials cycling, among others. Many questions remain about concept validity and practical application, but these concepts reveal some potential for application and many of the problems encountered in attempts to develop widely applicable indicators of environmental value.

Structure, Function, and Service, and Their Sustainability

The structural and functional properties of ecosystems define their component parts and processes, their diversity, their sustainability, and their response to influential forces originating from outside the ecosystem, such as solar radiation and gravity. Structure and function are characterized by biodiversity, which is the biologically derived variety that occurs in ecosystem form and dynamics. Genes are often said to be the most fundamental of ecosystem parts because they hold the information needed —the "architectural plans"—for sustaining all other ecosystem structure and function, and associated natural services. The genetic information in ecosystems is most typically indicated in the biodiversity expressed in species and communities. Thus biodiversity indicators of genetic scarcity, including its vulnerability to extinction, shows potential as an indicator of environmental resource value once their expression is matched with indicators of human service. A disproportionate amount of unique genetic information is sustained in relatively rare species. Biodiversity loss through human-caused acceleration of species extinction erodes ecosystem "design and maintenance" information held in genes, and the natural capacity of ecosystems to sustain the diverse structures and functions supporting all dependent ecosystem services and values. This erosion of biodiversity limits management options, precluding possibilities that are dependent on the extinct genes.

Ecosystem Integrity and Biodiversity Measures of Naturalness

Ecosystem integrity relates to the completeness of natural structure and function, usually as indicated by native biodiversity. Full integrity is exhibited under the conditions with which the ecosystem evolved, in the absence of modern human impact. In practice, the least modified of natural reference conditions is selected to anchor an index of ecosystem integrity in its maximum value. One of the purported hallmarks of natural integrity is the sustainability of natural ecosystem structure and function that results from self-regulation under evolutionary conditions. As natural integrity is lost, the remaining structure and function, and dependent natural services, tend to become less predictable. However, most ecosystem-level function and natural services associated with production, biomass and materials flow and recycling is associated with common species and erodes much more slowly than structure and functions that sustain unique genetic information.

Variation from natural integrity is determined by the observed biodiversity in an array of reference-ecosystem conditions approximating a range from fully natural to fully altered states. A multivariate measure of natural biodiversity is a more inclusive indicator of natural ecosystem integrity than a single-variable indicator such as number of species. In practice, the diversity of a species subset, such as fish or birds, is most commonly used to indicate ecosystem condition. Such measures can fall short of desired inclusiveness because they are incompletely representative of ecosystem habitat and community conditions. Less inclusive still are single-species indicators of ecosystem integrity.

Concept of Integrity In A System Context

Conceptual models of ecosystem integrity are least well developed at the landscape scale of structure and function important for recovery of local integrity loss following disturbance and sustaining ecosystem-wide integrity. Ignorance of the system context in the influential landscape distorts the evaluation of plan effectiveness in restoring and sustaining resource production. Local integrity can be restored, once lost, when all of the parts, processes, and recovery pathways connecting intact and locally disturbed areas are maintained. Ecosystem resilience—the capacity to "bounce back" from stressful disturbance—restores local integrity through habitat recolonization and community succession. Functional recovery ordinarily is more rapid and complete than structural recovery at a local site. Rare species colonize individual sites much less reliably than common species and their maintenance usually requires a larger area of intact natural integrity. Compared to common species, the colonization of specific sites by rare species appears to depend substantially more on random events.

Cultural Integrity and Ecosystem Health

The concept of natural ecosystem integrity emphasizes the connections among fully natural integrity, self-regulating functions, and sustainable states, but is less clear about relationships in less natural ecosystems. The concepts of "cultural integrity" and "ecosystem health" suggest that ecosystems can have numerous modified but sustainable states without being fully natural. Cultural integrity can exist locally and/or globally within the ecosystem. A locally modified portion of an ecosystem, say a waterway, can sustain function, once altered, albeit with a locally altered biodiversity. As more of the ecosystem is converted to human use, the natural attributes of ecosystems gradually erode and eventually threaten the sustainability of the rare and unique structure and function. A sustainable condition of cultural integrity and ecosystem health exists when enough natural integrity is maintained in the ecosystem to assure that recovery is possible anywhere in the ecosystem, if society so chooses. The most usual strategy used to restore cultural integrity and health locally is to improve habitat quality and connectivity within the physical limits of beneficial enhancements, such as improving clean water in modified waterways and harbors. This is most often achieved through structural engineering. In contrast, deficiencies in ecosystem integrity and health can be approached globally by restoring and sustaining the viability of all parts and processes contributing to natural integrity. This is most often achieved by removing the effects of past structural engineering.

Human demands for cultural development assures that most ecosystem restoration efforts will seek no more than partial restoration of the entire ecosystem, resulting in some mix of natural and human-modified properties. Even so, partial restoration is expected to lead to self-regulating functions and sustainable ecosystem states. The concepts of cultural integrity and ecosystem health are the basis of this expectation (which go back nearly a century in natural resource management). Expectations are complicated, however, by the growing realization that functions and structures respond to restoration at different rates.

Restoration Responses of Function and Structure

Ecosystem-level functions —such as production and biomass accumulation, materials cycling, and ecosystem resilience— are dominated by the performance of a few common species. The rare species provide some functional refinement and a lot of functional redundancy, which contributes to resilience following exceptionally intense disturbance. Partial restoration that recovers the common biodiversity typically captures a large fraction of the natural functions supporting many services may fail to restore much of the scare biodiversity expressing the unique genetic information held in ecosystems.

Much of the important function and service associated with maintaining unique genetic information is linked with globally scarce species. In addition to potential resource-development value, those species provide functional "backup" that replaces common species when ecosystems undergo exceptional stress. Scarce species are not missed in most ecosystem functions under ordinary conditions, but are significant for sustaining natural ecosystem resilience and management options well into the future. The scarcest resources globally (e.g., species vulnerable to extinction) are among the most significant of those resources, and the most challenging to restore. Recovery of scarce species involves much greater uncertainty and risk than the restoration of common species and associated functions. This risk is often a reason given to avoid targeting scarce species, especially in small restoration projects, and instead emphasizing restoration of more common function and structure. (That rational of course misses the restoration point entirely). A fundamental way to control such risk is to scale up the recovery of ecosystem resources to a more inclusive level of influential landscape and community composition. Of course that is more expensive.

Ecosystem Indicators of Resource Significance

Ecological concepts pertaining to naturalness, such as ecosystem integrity and natural biodiversity, are service-neutral constructs (where services are defined as things that ecosystems do which contribute to satisfying human wants and needs). Therefore, ecological indicators of naturalness will not necessarily indicate or track the types and levels of ecosystem services that may result from change to a more natural state. Concepts of ecosystem integrity and biodiversity gain service- and resource-significance meaning only after variations in ecosystem integrity and biodiversity are calibrated against variations in recognized service output from the same restoration action. The non-monetary metrics chosen for project evaluation should indicate the desired change in the resources. For example, the ecosystem service that sustains a rare species might better be measured as number of recruited adults than total number. Once resources of significance are recast as ecological indicators providing the desired service, models can be selected or built to forecast indicator-output response to with- and without-plan conditions. When the indicators of significance are not greater naturalness alone, these models will need to accommodate more than one measure of ecological output.

Regardless of whether greater naturalness alone is a significant resource response, Corps policy ordinarily expects a more natural (or naturalistic) condition to result. Indicators of naturalness and indicators of more specific resource significance can respond quite differently to restoration plans that propose only partial ecosystem restoration. Commonly used biodiversity indicators or other indicators of greater naturalness often are composed of the more common parts and processes in ecosystems while the parts and processes of greatest significance often are among the scarcest resources. The increment of naturalness indicated by a project plan may not be sufficient to support the increments of resource output and services that justify the restoration investment. These differences converge into one quality indicator as restoration approaches a fully restored ecosystem. If resources of significance are confidently associated with full restoration of ecosystem naturalness, any good indicator of full restoration will also confidently predict recovery of the resources of significance (but only with respect to completeness of knowledge about the natural reference conditions). When the proposed restoration is only partial, planning models and methods (and the evaluation framework more generally) need to account for a possible differential response of indicators of naturalness and indicators of significant resources in the range of humanly disturbed ecosystems over which the partial restoration is to occur.

A Widely Applicable Indicator of Environmental Value

No widely applicable non-monetary measure of change in environmental value exists, but there may be an inclusive measure of NER contribution, depending on how Corps policy is interpreted. Energy units, genes, or other universal measures of ecological product are too general to capture the different values perceived in their diverse expressions. Short of a full measure, and in keeping with the evaluation criteria for NER, the common biodiversity indicating the natural integrity of ecosystems is one possibility if the primary objective of restoration is simply greater naturalness of resources responding to habitat improvement. However, different values are likely to be placed on specific expressions of biodiversity by at least some stakeholders in the restoration result. Even if that were not the case, natural integrity does not seem to hold up to the need for a national-level of "standard-unit" measure. Whereas the biodiversity existing locally in an ecosystem can be gauged against fully natural sites within an ecosystem, no way to compare across ecosystems is evident. Two ecosystems of equal integrity can have very different biodiversities. It is also difficult to determine what increments of biodiversity mean in terms of their relative naturalness.

Corps policy indicates that the NER contribution is to be made up of ecological resources associated with "terrestrial and aquatic species", which includes numerous resources used for commodities, recreational, and aesthetic services, all of which are excluded by policy. A promising measure of NER contribution is based on the genetic uniqueness of scarce biodiversity in the form of species at risk of global extinction. The greater the uniqueness and vulnerability of species at risk, the greater is the deficiency in service and value based on future resource development and management options at risk of loss. Option value is not situational, and its indication in a uniqueness-vulnerability index can be made comparable within and across ecosystems at scales varying from local through national (or international) levels.

A uniqueness-vulnerability index (a natural currency) is presently conceivable (if crudely so to start) and is consistent with institutional, public, and technical indicators of significance, such as the Endangered Species Act and conservation status designations by the state natural heritage programs. Existing indicators of uniqueness/scarcity include various national and international "red lists" of species vulnerable to extinction. A leading source of such information is the database, NatureServe, that is maintained for the state natural heritage programs in the United States.

This uniqueness-vulnerability index falls far short of representing all value. This index is based on the relative scarcity of species traits and genetic information, and it places high value on maintenance of the scarcest species for future management options, including restoration options. It places very little value on common species, despite the many ecological services that are provided by common species (They dominate the production, biomass and other ecological process underlying many services). Most utilitarian values, including NED, are associated with relatively common species, such as the species that support hunting, fishing and much other outdoor recreation. Yet, there may also be services and values as yet to be revealed that fall outside this index and the NED monetary index to value. Until those values are revealed, however, a uniqueness-vulnerability index is a good interim measure of NER contribution worthy of serious consideration.

Model Use and Development

Section 4 describes and examines existing types of ecological models with respect to their applicability in ecosystem restoration planning.

Index Models

Corps environmental planning history has been much more closely tied to index models than to actual-output estimation models, despite a long history of developing actual output estimates for hydrologic analysis. The P&G provides only one substantial example of an ecosystem evaluation procedure, which is a single-species index model designed for impact mitigation analysis required by the National Environmental Policy Act. Many such species-habitat indexes were generated in the early 1980s, just in time for the new environmental improvement authority in 1986. Thus species-based index models quickly became the model of first resort. Other probable reasons for choosing them over actual estimation techniques include a deficiency of long-term ecological databases (unlike hydrologic databases), substantial Corps professional uncertainty in ecological theory and application, and a much more limited computing environment than now exists.

The most fundamental difficulty with species-habitat index models is that they typically are not inclusive enough of all community-habitat interactions. They are not indexed with respect to a fully natural ecosystem condition or to any other indication of naturalness, but instead are indexed with respect to variation from an optimum condition for the chosen species. Thus, the meaning of the index with respect to naturalness can be confusing and may lead to the development of plans that focus on artificial enhancement (rather than restoration) of habitats when the optimum habitat condition is targeted.

More recently, a number of community-level index models have been developed, at least in prototype, and offer a number of improvements over species-level models, because they are indexed to the most natural condition, rather than to some optimum habitat condition. Models used in the Index of Biotic Integrity, Wildlife Community Habitat Evaluation, and Riverine Community Habitat Assessment and Restoration Concept, for example, anchor their maximum index value to native species diversity or other native biodiversity measure existing in the most natural habitat state determined from existing reference conditions. This is also true for the ecosystem functional capacity index models of the Hydrogeomorphic approach, which are anchored in the most natural ecosystem state indicated by reference sites.

These direct measures of ecosystem naturalness can be useful for restoration planning to the extent that a more natural or naturalistic condition is integral to project objective achievement. However, unless the entire community is an ecological resource of national significance, or there is a known direct relationship between the community index and the condition of the significant resource, some other measure(s) of resource significance is needed to determine if the forecasted gain in naturalness is socially significant. For example, the habitat conditions input to a community or ecosystem model that achieve some increment of greater naturalness could be used for inputs to a second set of models that forecast the condition of specific significant resources (e.g., rare species, recreational species, change in water discharge). In this way, the second set of models would be used to evaluate the significance of the effect of restoring a more natural condition. Best use of models in this way demands a lot of a good concept model of the target ecosystem and choice of habitat inputs. Few existing models fully qualify for this level of use, but existing models can be adapted if carefully interpreted in the context of a good concept model.

A common deficiency of all existing index models, regardless of their indication of relative naturalness, is their focus on a local planning perspective. They tend to ignore large-scale landscape features and processes that can be very important for restoring and sustaining significant resources. They also tend to ignore the need to evaluate contributions of significant resources through a national perspective as well as the local perspective. The linkage to a national perspective is left for other methods (e.g., best professional judgment). These deficiencies could be addressed in development of future index models, but would be faced by substantial conceptual difficulty arising out of the interactions that occur between the size and patters of habitats in the modeled area and the quality of each unit of habitat in the area.

Actual Estimation Models

Actual estimation models include physical, statistical, and process models. Actual estimates of outputs have an obvious advantage for communicating expectations explicitly rather than implicitly based on knowledge of indexed reference conditions. Physical and statistical models have limited use in relatively simple restoration situations where the desired conditions and measures are quite obviously indicated in a basically intact natural setting with very little human impact. Unlike process models, they are not very flexible or portable.

Most process models also focus on local perspectives (e.g., lakes, wetlands, stream segments), but nevertheless provide many advantages, including the potential for incorporating complex interactions between size and patterns of the area models and interactions with quality of individual units of habitat. The most useful process models simulate dynamics in time and space. Their greatest shortcoming is their need for process understanding, which often is time consuming and expensive to obtain. However, they are unsurpassed for situations demanding explicit integration of non-linear relationships leading to multiple outputs and time dependent feedbacks. They are the most potentially useful when it is impossible to capture all benefits in a single ecological output indicator and multiple indicators are needed. Recent model advances enable simulations of spatial interactions at large scales.

Although process simulation models have no inherently better predictive attributes than other models, and less so than statistical models, their workings and outputs are more explicit, often making them superior communication tools for tradeoff analysis in controversial planning environments and for organizing a rigorous adaptive management framework. They are unsurpassed for organizing new information adaptively into the model structure as lessons are learned. Process models such as CASM, a lake ecosystem model, show a strong potential for developing generic ecosystem models (requiring local calibration). Other process-based models/methods, such as ATLSS, an Everglades restoration model, show the potential for representing spatial dynamics in outputs. Process models also show the greatest potential for comprehensive forecasting of those physical outputs underlying all economic and environmental consequences of plan implementation in multipurpose studies.

Picking The Best Model

Determining the best models for any restoration context depends on the complexity of ecosystem alteration that has occurred, the complexity of objectives to be achieved, and the risks that would be incurred if the ecosystem outputs should fail to become established as forecast. Just about any rigorously applied model type will suffice for situations where there has been very little ecosystem change from the natural state, the condition to be restored is closely connected to the restoration site, full restoration is targeted, the source of the deficiency in resources of significance is easily identified and removed, and the decisions are not controversial. As ecosystem and planning conditions grow more complicated, however, the advantages of process simulation models begin to outweigh the relative accessibility and cost advantages of index models.

Policy Standards for Plan Evaluation, Comparison and Selection

Section 5 reviews the Corps planning framework for ecosystem restoration by way of outlining the analytical framework used for traditional civil works missions, and how it has been adapted for restoration planning.

Economic Development Projects

Corps planning regulations for traditional civil works purposes define the federal objective in project planning as contributions to "National Economic Development' (NED) as represented by increases in the net economic value of goods and services. That is, traditional purposes are pursued based on a utilitarian philosophy that recognizes contributions to the satisfaction of human preferences as the ultimate goal of civil works activities. Following that standard, project plans must be evaluated in terms of their monetary (NED) costs and benefits, and used within a benefit-cost analytical framework to compare project plans in terms of net NED benefits (monetary benefits less costs). The recommended plan for federal action is to be the alternative plan that provides the greatest positive net benefits that is also consistent with environmental protection.

Ecosystem Restoration Projects

The plan evaluation, comparison and selection standards established by Corps regulations for the NER purpose different in several important ways from those applied to NED purposes. First, Corps regulations stipulate that restoration outputs must be measured in physical or biological units of some kind that reflect resource "value". Second, since NER outputs are to be measured in metrics that are incommensurable with money measures of project costs, benefit-cost analysis cannot be used to evaluate and select plans in terms of a net benefits criterion. Instead, Corps regulations require the use of "cost-effectiveness analysis" for plan comparison, in which the monetary costs of each alternative plan are weighed against the non-monetary level of NER output produced by the plan. Cost-effectiveness analysis provides a way to identify the set of cost-effective plans representing the least-cost means of producing different achievable levels of NER output. Further, Corps regulations specify that "incremental cost analysis" should be performed to identify the marginal cost per unit of output gained from moving from one cost-effective plan to the next higher-output, cost-effective plan. That analysis can help planners to identify plans for which the added NER output achievable may not justify the additional cost required to achieve it.

Together, cost-effectiveness and incremental cost analyses (CE/ICA) serve to narrow and illustrate tradeoffs among the set of NER plans considered for selection. But since plan costs and benefits are expressed in incommensurable terms, these analytical procedures cannot identify a "best" plan in an objective way comparable to the positive net benefits criterion used for the selection of NED project plans. Instead, Corps regulations say that restoration project plans can be selected based on a subjective determination that non-monetary outputs are worth monetary costs, provided that the selected plan is cost-effective and NER outputs are shown to be "significant" based on institutional, public, or technical recognition of importance.

Multipurpose NED/NER Projects

For multipurpose NED/NER projects, Corps policy says that plan selection shall attempt to maximize the difference between project benefits--both NED (monetary) and NER (non-monetary)—and project costs, and strike the best balance between the two objectives. As in the single purpose NER context, this justification standard necessarily requires a subjective determination of the 'best" plan since NER outputs and NED effects (benefits and costs) are evaluated and expressed in different metrics.

Planning guidance suggests that the evaluation and comparison of NED/NER plans should rely on a combination of benefit-cost analysis for the NED purpose, and CE/ICA for the NER purpose. However, that would not possible when plans are characterized by joint costs – or costs that simultaneously produce both NED and NER outputs. Joint costs should be common for NED/NER projects since the primary rationale for pursuing a multipurpose project instead of separate single purpose projects is potential efficiencies that can be realized by exploiting opportunities to jointly produce desired outputs. If a dollar's worth of plan costs serves both NED and NER outputs, these costs and benefits must be considered together for plan comparison. This can be readily accomplished since plan costs and NED benefits are both measured in dollars and are recognized by Corps regulations as fungible (i.e., a dollar's worth of benefit for a formulated NED purpose exactly offsets a dollar's worth of plan cost). Given this, the CE/ICA framework can be implemented using a measure of *net* plan costs calculated by subtracting NED benefits yielded by the plan from the financial costs of implementing the plan.

A slightly different approach for analyzing the economic efficiency implications of NED/NER plans would extend the two-criteria cost-effectiveness framework to one defined over multiple criteria. So, for example, in a planning case in which plans have been evaluated in terms NED benefits, implementation costs, and a single measure of NER output, an efficiency analysis based on these three criteria would identify the set of plans for which more NER output could not be obtained through choice of another plan without realizing higher plan costs or lower NED benefits. This framework is also appropriate in the single or multipurpose planning case in which NER outputs are evaluated in multiple, incommensurable metrics.

Potential for Monetary Evaluation of Restoration Outputs

Section 6 reviews and assesses the potential use of a monetary standard for evaluating restoration plans, including the possibility that the benefit-cost analytical framework used to compare and recommend traditional civil works project plans could be applied to the ecosystem restoration context.

The concept of economic value rests on the presumption that the welfare of any individual derives from the satisfaction of that individual's preferences. Acceptance of that premise implies that the tradeoffs that a person makes as he or she chooses less of one good in favor or more of another good reveals something about the economic value of this tradeoff to the individual. Formally, the economic value of some change (tradeoff) to an affected individual is the amount of monetary compensation (positive or negative) that the individual would need in order to maintain the same level of preference satisfaction with the change as without the change. The conceptually valid measures of economic value for some policy change are "willingness to pay" (WTP) compensation for policy benefits, and "willingness to accept" (WTA) compensation for policy costs. Total benefits are defined as the sum of WTP estimates for each individual who stands to gain from the new policy, and total costs are defined as the sum of WTA for each individual who stands to lose from the new policy.

Measurement of Economic Value

Use of a benefit-cost analytical framework for evaluating ecosystem restoration plan alternatives would require an accounting of the total economic value associated with the expected change in all of the service flows resulting from those plans. Market prices provide the basis for estimating economic values associated with changes in the flow of goods and services that are traded in competitive markets. But since ecosystem services generally are not traded in markets, there exist no market prices that can be exploited to estimate the economic value of changes in service flows. To address this limitation, economic methods have been developed to estimate "shadow values" for non-market services that, in theory, represent the market prices for services that would emerge if the services were traded in competitive markets.

NED Evaluation of Traditional Outputs

The Corps has long faced the need for non-market valuation since traditional civil works outputs generally are not traded in competitive markets. However, many traditional outputs have close market counterparts that facilitate benefits estimation based on *change in net income*. So, for example, the benefits from enhancing waterway transportation links are assessed as cost savings to commercial navigation shippers, and the benefits from enhancing flood regulation services are valued in terms of property damages avoided. Similarly, the benefits of new sources of water supply and hydropower can be estimated based on the *cost of the most likely alternative*.

In general, the valuation of traditional civil works outputs such as commercial navigation, flood control, hydropower and water supply has been readily possible for two main reasons. First, changes in the underlying ecosystem service flows (waterway transportation links, flood storage and diversion capacity) resulting from management action are intensive and largely involve physical relationships that are well understood and predictable. Thus, for many traditional outputs the types of non-economic information needed for valuation is readily obtained. Second, as outlined above, these outputs generally have close market counterparts that provide market evidence of economic value.

NED Evaluation of Restoration Outputs

In general, the economic techniques outlined by Corps guidance for valuing traditional civil works outputs are also applicable to estimating values for the types of natural service outputs likely to be associated with ecosystem restoration. This does not mean that valuation prospects for restoration outputs are generally favorable, however. Indeed, the information needed for valuation in this context is often not readily estimable. Restoration effects on natural ecosystem services are often subtle and involve complex biological relationships that are not well understood and predictable. These factors impede development of the non-economic information needed for valuation. And natural services often affect human welfare in ways that have no close connection to the use of market goods. In the extreme, people may hold “passive use values” associated with the knowledge of the existence of certain ecosystem services (e.g., sustenance of endangered species) independent of current or anticipated future use of these services. These factors severely limit the extent to which market data can be exploited to infer values for restoration outputs.

In addition to these technical hurdles, some economists and other professionals argue that the utilitarian concept of economic value does not tell us everything we need to know about the desirability of environmental protection and restoration activities. Challenges from these critics could be expected to hinder the political acceptability of adopting a framework for restoration planning that turns on the economic valuation of restoration outputs.

Nevertheless, in some cases it should be technically possible to estimate economic values for certain restoration effects that could be used to inform decision making in ways that are politically acceptable. An obvious example is when restoration project plans measurably affect traditional NED outputs such as flood regulation. In such cases, these effects should be valued and used within the CE/ICA framework for evaluating and comparing alternative project plans in terms of net monetary effects and non-monetary, ecological effects.

A Strategy for Improving Environmental Benefits Analysis

Section 7 presents conclusions and a draft strategy for improving environmental benefits analysis, including immediate, intermediate and long-range components that address models and methods, capabilities in using models, and policy and guidance.

Conclusions

The study discovered no universal unit for expressing ecosystem restoration benefits in non-monetary terms that can adequately evaluate the full range of restoration plan effects. However, the notion of "biodiversity associated with scarce species" (as defined by uniqueness and vulnerability) could be pursued to develop a standard non-monetary measure of resource significance that could help discriminate among NER investment choices.

This notion of "scarce species biodiversity" can be distinguished from the more comprehensive concept of biodiversity in that it focuses on that subset of species, communities, guilds and ecosystems designated to be of *significance* because the loss of their unique traits to extinction would be irreplaceable. This significance is technically identified in numerous scientific reports, including the work of the WWF, TNC, and state natural heritage programs. It is also indicated institutionally by the Endangered Species Act, which establishes a national objective to recover threatened and endangered species and necessary habitat support to an unlisted status. Pursuing this measure would be compatible with the habitat-based emphasis of the current Corps policy, and with the policy emphasis on resource scarcity as an indicator of significance. The standard units (see discussion in Section 3) would be based on characteristics of vulnerability and uniqueness, using methods developed by conservation biologists, and taking into account global rather than only localized significance. For example, while some significance may be inferred by plans supporting the North American Waterfowl Management Plan, greater significance would be attributed to plans that support a species such as black ducks, which are rare compared to mallards, which are included in the plan but are neither rare nor vulnerable.

Such "scarce species biodiversity" may not be the only relevant measure of resource significance that contributes to NER output, but placing emphasis and priority on such outputs can be supported because the recovery and protection of scarce resources determines the limits of future management options, including restoration options.

The study also found that a variety of ecological models are useful in formulating and justifying ecosystem restoration investments based on forecasts of ecosystem-level conditions (with more or less human effect) and specific outputs of significant resources. The models can be usefully applied alone or in combination, depending on the circumstances. In the near term, a combination of community-habitat index models that forecast naturalness (including those such as IBI), and species-habitat index models that forecast suitability of the more natural state for specific resources of significance can provide a sound basis for evaluating plan effects. In those instances where *the more natural condition in itself* is identified as the resource of social significance, ecosystem-level biodiversity models and methods that are habitat based (e.g., IBI, WCHE, HGM) may serve satisfactorily, once calibrated. Model selection depends on the extent to which a more natural condition or more resources of significance should guide restoration formulation and evaluation. Corps guidance is not as clear as it could be regarding desired outcomes of degrees of natural conditions versus resources of significance.

This conclusion does not, however, address the limitation that habitat-based indicators of NER benefit are unlikely to capture all of the Federal interest affected by restoration plans (as noted by the NRC). In addition, relatively few species-habitat models have been specifically developed for rare resources. Other models, such as functional capacity indices (e.g. HGM, water storage, organic export) and process simulation models (CASM) are applicable for the multi-output analysis of benefits that appears to be required for multipurpose planning. Ecosystem process models have the advantage of generating more theoretically defensible and explicit results unsurpassed for communication and adaptive management, but are more costly. All existing models have shortcomings requiring substantial development effort, but especially so for the process simulation models.

The study also concludes that significant technical obstacles preclude the economic valuation of all possible restoration outcomes that could potentially be evaluated in monetary terms. Furthermore, whether or not the utilitarian concept of economic value is the appropriate standard of “value” for evaluating restoration outcomes is open to question. Economic value may not indicate everything that stakeholders need to know about the desirability of restoration projects. This suggests that the current policy guidance that recognizes non-monetary NER outcomes as a category of effects separate from monetary effects is appropriate for evaluating restoration projects. However, a greater level of policy clarity is probably needed to help planners determine the appropriate restoration objectives and valuation standards for restoration planning.

Use of evaluation criteria that includes both non-monetary and monetary effects does not reduce the need for efficiency analysis in the NER planning context, and this need is recognized by Corps guidance. The cost-effectiveness analytical framework for single-purpose NER planning is very useful for evaluating the opportunity costs and marginal tradeoffs among alternative plans. That framework, which is essentially equivalent to the old P&S efficiency framework that plotted net NED effects against some measure of environmental quality change, is also applicable to multipurpose NED/NER planning, and can be readily extended to a multiple criteria efficiency analysis when NER outputs are best expressed in multiple, non-commensurate metrics. The cost effectiveness framework is less discriminating as the number of choice criteria increases, making identification of more inclusive metrics an important pursuit. A focus for improving ecosystem restoration benefits analysis in the near term is to identify the monetary and non-monetary indicators of output needed to capture all significant effects, and ultimately to reduce them down to the minimum achievable.

Strategy

Preliminary ideas for a multi-component, three-stage strategy for improving environment benefits analysis are offered for consideration. The proposed strategy involves overlapping (I) *near-term, (II) intermediate,* and *(III) long-term* components. Within each component is attention to model development, staff model application capabilities, and policy and guidance issues. All three components would start as soon as possible, but would begin to produce useful results on different time horizons. The extent and timeliness of result will depend on initiation dates, investment levels, and concentration of effort. A number of ongoing efforts are identified that will or could contribute to this strategy in the Section 7 strategy discussion.

The *near-term* or **Incremental** stage (2 to 3 year horizon), addresses the requirements of the current Corps planning regulations, seeks modest advances in improving environmental models, and emphasizes improving staff selection, adaptation and application of a broader set of existing ecological assessment models. Broadening staff proficiency should enable more informed application of new models as they are developed, in addition to improving environmental benefits analysis now.

- Modest model improvements would be made by moving from reliance on single-species index models alone, to greater use of community-based index models, either alone or in combination with single-species index models. Ongoing efforts within the EMRRP program, such as the development of templates for community-index models, should contribute to such improvements in the near term.

- A protocol is being developed for selecting ecological assessment models and methods for use in ecosystem restoration planning. It will be published as a reference guide that summarizes different model types, attributes, limitations, and utility in the 6-step, Corps planning process.

- Concepts of and approaches to environmental benefits analysis need to be incorporated into a number of courses, workshops and other forums, at appropriate levels of detail, including the new Planner Core Curriculum, as well as over a dozen PROSPECT courses. Collaboration among IWR staff and Corps course instructors will help assure consistency and comprehensiveness in course instruction material refinement and presentation.

- A web-based tool catalog is being developed as part of the SMART R&D program. Both this effort and the model selection reference are likely to be linked within the web-based EMRIS system, assuming sustained funding support for the efforts.

- Workshops to apply the model-selection reference document to actual studies in a district would help improve district staff capabilities, inform invited staff from other agencies, and refine the instruction material for use in future courses and workshops.

- Future policy and guidance refinement should explicitly consider the issues raised by the discussions of ecological and methodological concepts presented in this report. They provide a theoretical basis, and identify some unresolved issues for informing improvement of NER evaluation.

- The NER concept is being examined in a FY03 policy study as a federal objective and basis for formulating ecosystem restoration projects. The NER study will examine the potential usefulness of the concept of ecosystem services for defining NER as a formulation construct and for developing a set of standard methods and metrics for characterizing and evaluating NER outputs

The *intermediate*, or **Next Generation** stage (5-year horizon), would pursue a fundamental rethinking of the NER objective and desired outputs. It would more intensely pursue the idea that ecosystems provide significant mixes of ecological services, the benefits from which can be compared with traditional NED outputs, and the possible advantages and practicality of defining an NER account that specifies these services. Further, it would seek to improve the ability to simultaneously evaluate multiple outputs indicating resources and services though the use of ecosystem process simulation models at proper landscape scales. New analytical frameworks for multipurpose NED/NER planning would be explored, including the opportunity-cost framework recommended by the *Principles and Standards* several decades ago for evaluating tradeoffs between economic and non-monetary environmental effects.

- Efforts to develop and refine ecosystem process models to forecast resource responses and associated outputs to restoration alternatives should closely consider the evaluation frameworks used in Corps planning, and inform the further evolution of those frameworks.

- Future efforts should investigate the development of a metric based on the biodiversity of scarce species, and its usefulness in determining the significance of forecasted NER plan contributions to significant resources.

- Research programs such as the EMRRP, SMART and TOWNS, and the newly formed Environmental Modeling and System-wide Assessment Center (EMSAC), along with the EMRIS system, could play key roles expanding the applications of existing models and developing new models. These programs need to be refined to more effectively address issues pertaining to environmental benefits analysis identified and examined in this study.

- Proposed work within the EMRRP ('04) would develop a framework that links habitat analysis, dynamic process modeling, and spatial statistics for application in aquatic systems.

- Potential applications of the Ecosystem Functions Model (EFM) beyond the Sacramento-San Joaquin basin, as well as the Watershed Analysis Tool (WAT) being developed as part of the Flood and Coastal Systems R&D initiative should be explored for potential advancements in ecosystem restoration planning.

- The formation of *model application assistance teams* could facilitate improving model selection and use of model output information in investment and management decision making.

- Policy and guidance efforts during this stage would further refine the NER concept and outputs, relative to ecosystem goods and services, along with alterative analytical frameworks useful in Corps planning, especially for joint NED/NER projects. Emphasis would be placed on better integration of project development, including ecosystem restoration, in its landscape context, to better serve the NED/NER Federal objective.

- The potential applicability of the concept of *ecosystem services* in water resources planning would be further explored for its usefulness in differentiating NED and NER and assuring that all of the monetary and non-monetary costs and benefits are considered.

- Procedures should consider the "sustainability" philosophy expressed in the PCSD (1996), and evolving through implementation of the Environmental Operating Principles.

- A broader notion of environmental analysis should be considered, which integrates the "NEPA process" into the P&G/P&S planning process, eliminating differing standards and principles for evaluation for ecosystem restoration planning and environmental impact assessment.

Over a *longer-term* (beyond a 10-year horizon), efforts could be made to explore more comprehensive economic valuation of ecosystem services. This **Monetization** stage would attempt to link ecological process simulation with economic valuation methods for the evaluation of restoration outcomes in economic terms. If deemed practical and acceptable, this might ultimately lead to the development of standard analytical tools that would allow more NER outcomes to be evaluated in NED terms, thereby reducing the total number of non-commensurate choice criteria that would need to be considered for efficiency analysis.

- Technical obstacles to comprehensive monetary accounting of restoration benefits need careful consideration, including the uncertainties associated with forecasting ecological outputs from alternative plans and the limitations in methods for measuring non-market benefits of service outcomes that affect the quality of human life in ways that have no close connection to the use of marketed goods.

- Also to be considered are challenges from critics who question the acceptability of economic valuation for environmental benefits, which could hinder the political acceptability of adopting a monetary standard for evaluating and justifying restoration projects.

- To the extent possible, the Corps should pursue the environmental benefits analysis improvement strategy in conjunction with other Federal and state agencies that can contribute to and benefit from these efforts.

- Ongoing work within the Decision Methodologies Research Program will contribute to this pursuit. These include identifying recent and ongoing district studies that monetized environmental outputs, identifying applications in other agencies, and a literature review. Additionally, a test case has been proposed that would apply monetization to a completed ecosystem restoration project, to examine whether and how this information could have been useful in decision making. The potential analysis of air quality benefits, from reduced emissions attributed to inland waterway shipping relative to land-based transportation modes is also being examined.